Technical Manpower for the Next Hundred Years

J. R. WEIR

A long-range view of world needs—considering such factors as population expansion, food and energy requirements, natural resources, and the rise in standard of living—indicates that the technical manpower shortage is here to stay.

THE ECONOMICS of technical brainpower in a modern industrial civilization continues to grow in importance. In fact, it seems quite possible that the number and quality of trained technologists available to the nations of the world will determine the rate at which standards of living can be raised, the rate at which underdeveloped nations can industrialize, and the rate at which we can build the educational facilities so necessary for survival in an atomic age.

In considering this problem, I should like to describe some of the more important trends that have contributed to our present short supply of scientists and engineers and then see what conclusions we might arrive at by projecting them into the next century. I will leave to Mr. Ingram, in the article which follows, the more difficult task of making specific recommendations on how the current technical manpower shortage might be alleviated.

For at least half a billion years, man's working skills and knowledge were very limited. For all but the last two centuries of recorded history, only a small minority of the working force in any society was made up of skilled craftsmen. The majority were farmers, tradesmen, and unskilled laborers, and almost any lifetime occupation required little ability and could be learned without formal education. But this began to change during the 18th Century with the Industrial Revolution and the beginning of the Scientific Era. Now the skilled mechanic, the inventor, the engineer and the scientist came into being. As increased knowledge of the physical world permitted increased industrialization, the need for highly trained workers and for professional scientists and engineers also increased. At the same time, the demand for farmers and unskilled laborers progressively declined.

For example, in the United States in 1900 there were 11 million farmers; in 1950, there were only 7.5 million. Yet in 1900 they represented 38% of a working force of 28 million, while in 1950 they represented only 13% of a labor force doubled to 60 million.

Even greater changes occurred among the professions. In 1900, 1 million professional and technical workers made up 4½% of the labor force. By 1950 this group had increased fourfold, and now it constituted 7½% of the working force.

A current report of the Department of Labor notes that for the first time in the history of the United States the number of persons employed as professional, office, and sales workers exceeds the number employed in manual occupations. The Department predicts a growth rate for professional and technical workers that is nearly double that of any other occupational group. They expect no change among unskilled workers and a decline among farm workers.

These figures suggest that the current shortage of engineers and scientists is but one aspect of a larger and more general problem: the absolute necessity for a large variety of highly skilled manpower in order to develop and operate a complex industrial civilization. These long-term changes in the composition of the labor force as our nation went from an agricultural to an industrial economy provide a basis for forecasting world-wide manpower needs for the future. Many of the factors that produced them are obscure and exceedingly complex, but a consideration of just a few of the more obvious ones will, I think, lead us inevitably to the conclusion that the demand for scientific and engineering know-how, for technical brainpower, will continue to increase for many years to come.

Let us look first at what is perhaps the most powerful element in the whole system: the pressure of increasing world population.

This is a matter that is receiving extensive publicity and certainly needs no detailed documentation here. A few general figures will indicate the nature of the problem and the magnitude it is likely to assume.

It has been estimated that the population of the earth in the year 1000 was about 300 million. It had taken something like a million years to reach this figure. Only by about 1830 did the human race reach 1 billion in number. By 1930, 100 years later, the second billion was added. It will take 35 years to add the third billion; we will reach it in 1965. The United Nations estimates it will take 15 years to add the fourth and 10 to add the fifth. By the turn of the century we should be 6 billion strong, or perhaps I should say 6 billion thick!

Clearly world population is not only increasing rapidly, but of even greater significance, the rate of increase

Full text of a conference paper presented at the AIEE Fall General Meeting, Chicago, Ill., Oct. 9-14, 1960. Recommended for publication by the AIEE Management Committee.

J. R. Weir is with the California Institute of Technology, Pasadena, Calif.

is growing rapidly as well. Between 1850 and 1900, world populations grew by about 0.7% per year, a rate that doubled the population every century. Between 1900 and 1950, the average annual rate of increase was 0.9%, shortening the doubling time to about 75 years. The projections for the period 1940 to 1980 predict a rate of increase of 1.3%, or a doubling time of only 50 years. Will there be 6 or 7 billion people by the end of this century, and perhaps 12 to 14 billion by 2050?

These figures indicate a doubling of world population within the lifetime of many of us here today. But they also suggest an increase in the need for technological services far beyond a mere doubling of present demand.

FOOD PRODUCTION

THE SECOND FACTOR to be considered is food production. It seems probable that a large proportion of the human race has never had enough to eat. Starvation and famine have existed throughout recorded history and continue to exist in many areas of the world today.

In the period from 1900 to the beginning of World War II, total world food production increased 10 to 15%. But in the same period of time world population increased 30%. The war decreased food supplies over most of the earth's surface and the prewar level was not regained until 1952; but by this time there were, of course, even more people to feed.

So there are more hungry people in the world today than ever before and they seem to be getting hungrier. Austin White's figures indicate the average daily food intake for French and English prisoners of war and convicts in America in colonial times was 2,735 calories per day. The United Nations estimates 55% of today's world population gets less than 2,250 calories per day, and an additional 25% between 2,250 and 2,750 calories per day. Three quarters of the people of the modern world get less food than the prisoners and convicts of two centuries ago.

There are increasingly insistent demands from these hungry people that they receive more food, and recent political and economic revolutions give strong support to the view that these demands will be met, hopefully in a peaceful manner.

James Bonner has calculated that a full application of modern agricultural technology, if applied to all the cultivable areas of the world, could produce sufficient food to provide an adequate diet for the 6 or 7 billion people that will populate the earth by the turn of the century. However, such application would require the spreading of the science and technology of farming to all parts of the world. It would require facilities for worldwide agricultural education, factories for the manufacture of fertilizers, tractors, insecticides, etc., and the irrigation of most of the arid regions of the earth. It would also require a continuing program of basic and applied research on agricultural problems. The necessary technology is now available; only its application by trained technicians remains to be accomplished, a task requiring thousands of engineers and scientists.

MATERIAL RESOURCES

UP TO the last century or two, raw materials, our third factor, have assumed a relatively unimportant part in man's struggle for survival. He fashioned a few artifacts from relatively pure metals which he found lying on the surface of the earth; his extremely limited knowledge of metallurgy prevented him from exploiting less pure deposits. This was equally true for outcroppings of all minerals and for surface deposits of coal and petroleum. He could make only very primitive use of them.

This situation changed with the invention of the Scientific Method and the advent of the Industrial Revolution. The discovery of the scientific principles governing the physical world enabled man to release the energy in coal and oil and harness it to machines for productive work. As industrial processes were developed the demand for raw materials increased rapidly and forced the development of techniques for obtaining raw materials from less pure sources.

For example, primitive man could pick up almost pure copper lying on the surface of the earth. However, as the demand for copper increased with growing industrialization, it became necessary to go to lower grade ore. By the beginning of this century we were processing copper ore with an average concentration of 5% copper. Today this has dropped to 0.8% and we can certainly look forward to its dropping even lower, perhaps to 0.1 or even 0.01%.

Technologically, there is essentially no lower limit to the grade of an ore which can be processed. Ordinary igneous rocks contain most of the elements necessary for the perpetuation of a highly industrialized society, and in proportions which are not unreasonable from the point of view of industrial needs. For example, 100 tons of average igneous rock contains about 8 tons of aluminum, 5 tons of iron, 180 pounds of manganese, 40 pounds of nickel, 20 pounds of copper, and 4 pounds of lead. Many of the elements which are not found in sufficient quantity in igneous rocks, such as chlorine, bromine, and iodine, can be found in the oceans. Other elements, such as nitrogen and oxygen, are readily available in the atmosphere. Still others can be found in the practically inexhaustible supplies of limestone (a source of carbon), gypsum (a source of sulfur), and phosphate rock (a source of phosphorus). Given the necessary energy and enough technologists to develop the processes of extraction, the people of the world could, if need be, support themselves entirely with the leanest of ores, the waters of the oceans, the rocks of the earth's crust, and the air around them.

The fourth factor is the level of industrialization and the accompanying standard of living.

Before the Industrial Revolution, the manufacture of consumer goods was insignificant and limited to products that could be made by hand. Many man-hours and relatively few raw materials were consumed in the production of the barest essentials needed for a meager existence. The machines of the Industrial Revolution altered this in a most profound way. The individual machine operator could produce many times more than the hand craftsman and with much less effort. This meant greater quantities, greater variety, and lower prices, but it also meant increased consumption of energy and raw materials. An industrialized nation, as compared with an unindustrialized one, consumes energy and raw materials in prodigious quantities.

For example, per capita annual steel production in India is about 9 pounds per person; in the United States, it is 1,300 pounds. India consumes 1/10 barrel of oil per person per year; the U.S., 170 times as much.

Obviously it takes great technological know-how to design and build the equipment necessary to consume such quantities of raw materials as we do in the United States. When U. S. levels of consumption are considered in conjunction with the demand of underdeveloped countries that they be helped to industrialize, the magnitude of the problem becomes distressingly clear.

For example, if the present proportion of world population now living at extremely low levels of consumption—approximately 2 billion persons—were to be brought up to the standard of living of contemporary United States, we would have to extract from the earth 18 billion tons of iron, 300 million tons of copper, 300 million tons of lead, 200 million tons of zinc, 30 million tons of tin, in addition to huge quantities of other metals and nonmetals. These are totals well over 100 times the present world annual rate of production. These quantities of copper, lead, zinc, and tin are considerably greater than could be removed from all measured, indicated, and inferred world reserves of ores of these metals.

From these figures I think we might infer that the need for technical brainpower necessary to meet just the minimum expected demands for higher standards of living in underdeveloped countries will certainly overtax present world manpower resources.

ENERGY

It takes energy to extract metals from low-grade ores; it takes energy to manufacture equipment and to run it; it takes energy to produce food. Current world energy consumption from the three major sources—coal, petroleum, and natural gas—is equivalent to about 3.7 billion tons of coal per year. If all the people of the world were to expend energy at the per capita rate at which we do in the United States, consumption would increase sixfold to the equivalent of approximately 22 billion tons of coal each year. This is a rate of consumption that would exhaust the fossil fuel reserves of the world in 40 or 50 years. But it is also a rate dictated by the U. S. standard of living, a standard of living envied and sought by the rest of the world with increasing aggressiveness.

Certainly, if these demands are to be met we must develop other sources of energy, and it seems possible to do so from nuclear fission. Harrison Brown has calculated that in every ton of ordinary granite, energy which is equivalent to about 15 tons of coal can be economically extracted in the form of localized uranium and thorium. This means that from the long-range point of view man will be able, if it becomes necessary, to extract his energy needs from the very rocks of the earth's crust, the same rocks that can supply the variety of metals needed for the support of a highly industrialized world civilization.

Once again the ultimate problem is the development and application of the scientific and engineering know-how, the know-how necessary to develop the processes for the consumption of such vast quantities of energy.

The sixth and final factor is that of the ever-increasing complexity of modern industrial civilization. This contributor to the rising demand for technical brainpower, while not as easily documented as the preceding five, seems to be as important and as inevitable as the others. As populations increase, we see it in the emergence of more complex social, political, and economic systems. As the standard of living rises, we see it in more complex production, transportation, and consumption facilities. We see it in the increased specialization of occupations. We see it in the rapidly increasing complexity of scientific technology. This ever-increasing complexity—of knowledge, of human needs, and of human organization—is traceable throughout the recorded history of man and appears to be an inevitable consequence of a scientific–industrial civilization. Unfortunately it also consumes the attention and energies of highly trained manpower, both technical and nontechnical. Consequently, one is again forced to the conclusion that this source of demand for scientists and engineers can only increase in the future, also exponentially.

In very general terms, then, the situation seems clear, and extremely challenging. Exploding populations of hungry and deprived people are demanding equal access to the resources of the earth. They affirm their right to a standard of health and comfort comparable with the third of the world's population that makes up its privileged peoples, and we have seen that the achievement of this goal is technologically possible.

They can be denied their rights and held in subjugation, for a while at least, or they can be helped to achieve their objectives wherever possible. The Free World, and especially the United States, has chosen the latter alternative and is already committed to a program of technical assistance. It seems to me there is no alternative in the long run. However, this means spending increasing amounts of energy to produce greater quantities of goods from lower and lower grade raw materials for more and more people, and building the complex facilities and organizations necessary for an industrial civilization that will encompass the entire earth.

This is a situation that is unique in the history of mankind. It is the consequence of the evolution of technical–industrial society. It has no parallel in the past and leads one to an inescapable conclusion for the future: The demand for technical know-how must inevitably increase for many decades and perhaps centuries to come, probably at a geometric rate. Whether we like it or not, the technical manpower "shortage" will be with us from here on.